

## The Activities of Anak Krakatau Volcano during the Years of 1992 - 1996

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### Synopsis

The 1992-1996 eruption of Anak Krakatau, Sunda Strait, South Lampung, Indonesia, began on November 8, 1992, less than four days after a swarm of volcanic earthquakes struck beneath the volcano, which has recorded by one unit of PS-2 seismograph telemetric system.

Elevated levels of seismicity were first observed on August 17, 1992, and the seismicity rapidly developed into an intense swarm of volcanic earthquakes on November 8. More than 400 volcanic earthquakes smaller than magnitude 2 were recorded in the 10 hours before the first eruption on November 8.

A major explosive eruption occurred on November 13 that opened a new vent in the north part of the summit and followed by the first lava flow flowing to the north coast. The seismicity level was highly variable from November 13. It consisted of periods of intense seismicity associated with explosive activity. The initial explosive episodes were preceded and accompanied by shallow earthquakes of a low-frequency type (B-type).

Tephra from the explosions spread surrounding the volcano island of Anak Krakatau and not affected the inhabitant areas of South Lampung and Banten, even the other islands around the volcano island. The eruption materials built a new cone and added the summit of the volcano as high as 100 meters, and the approximate highest peak reached 300 meters above sea level.

The eruption continued until today and did not produce as much erupted material. In July 1996, the vent developed into three eruption points in a row direction to the north from the main vent. The northeast vent produced a large lava flow which flowed to the west and north coasts. During the four years activity, the eruptions produced more than 12 millions cubic meters of erupted materials that was calculated from the loss materials and lavaflows.

**Keywords:** Anak Krakatau volcano; volcanic activity; volcanic earthquake; precursory phenomena; explosive eruption; lava flow

### 1. Introduction

Anak Krakatau (Child of Krakatau) volcano lies in the Sunda Strait, South Lampung, Sumatra, Indonesia (Fig. 1), an active volcano in the volcanic arc that extends 7,000 km from northern Sumatra along Sumatra, Java, Nusa Tenggara, Maluku to the north of Sulawesi. At least one volcano in the arc erupt on average each year. Since its birth in 1929 to

1996 has erupted at least seventy eight times showing an explosive or effusive activity. Anak Krakatau is a volcano island, lies in the center of the Krakatau Volcanic Complex with estimated height in 1996 of about 300 m above sea level. It is constructed of alternating layers of lava and pyroclastic deposits that formed since 1930. The Krakatau Volcanic Complex consists of Rakata, Sertung, Panjang and Anak Krakatau islands. The first three islands are remnant

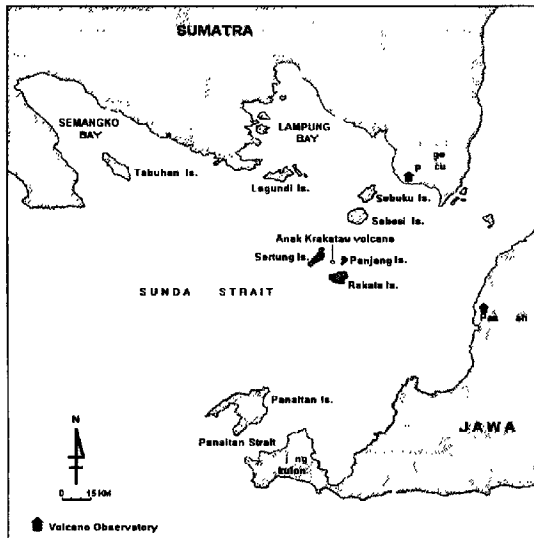


Fig. 1 Index map showing location of the Anak Krakatau volcano in Sunda Strait between Jawa and Sumatra Islands.

of the caldera collapse of the supposed Ancient Krakatau, and Rakata island itself is volcano that grow up together with Danan and Perbuwatan volcanoes before the cataclysmic eruption of 1883.

This volcanic complex is not occupied by inhabitant, but the area became into a turist attraction object applying for scientific research or enjoying natural scenes. To mitigate this activity, the Volcanological Survey of Indonesia has installed one unit of the seismograph telemetric system which observed from Krakatau Volcano Observatory, located in Pasauran village, Serang, West Jawa with a distance of about 45 km away from the volcano. In the middle of 1995, VSI has built another observatory that located in Hargopancuran village, Kalianda, South Lampung Regency.

Today Anak Krakatau is being built by current activity from the everyday ash explosions and lava flows forming a new cone and extending the area.

## 2. Eruptive History

Krakatau was well known and became famous in the world because of the paroxysmal eruption on August 27, 1883 and it was considered to a great event of the eruptive history, which has erupted more than 18 cubic km of ash with ash column of about 80

km high, and rose tsunami as high as 30 m along the west coast of Banten and south coast of Lampung. Although at that times the big cities have not developed as such today, but 295 small towns were swept by tsunami and killed 36,417 people (Verbeek, 1884).

Krakatau began to know in the eruptive history when the giant eruption occurred in 416 BC, which caused a tsunami and formed a caldera (Judd, 1889). Furthermore De Neve (1981) noted some informations that before the second paroxysmal occurred in 1883, several large eruptions of Krakatau arose in the enturies of 3, 9, 10, 11, 12, 14, 16 and 17 which were followed by growing up of Rakata, Danan and Perbuwatan volcanoes. This volcanic activity stopped in 1681.

After reposing of about 200 years, Krakatau began to indicate it's activity which has preceded by the eruptions of Danan and Perbuwatan volcanoes. On May 20, 1883 the eruption of Perbuwatan volcano with basaltic composition, initiated a paroxysmal explosion on August 27, 1883 which has dacitic composition ( $SiO_2 = 64 - 68$  percent) (Neumann van Padang, 1951).

Second repose period of Krakatau began in February 1884 to December 1927, when the first phase of eruption on December 29, 1927 occurred as a submarine explosions in the center of Krakatau Volcanic Complex. The visible phenomena of the eruption comprised bubblings and fountains of sea-water (Stehn, 1929a). He observed on January 20, 1929 the crater-rim appeared east of the eruption point, consisting of ashes, lapilli, loose block. It formed an island above the water and was named "Anak Krakatau" (Child of Krakatau). The eruptions continued until February 15, 1929 where the explosion columns reached a height of 800 m.

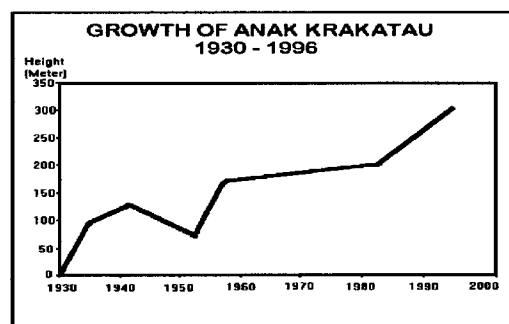


Fig. 2 Growth of Anak Krakatau since its birth 1929 to 1996.

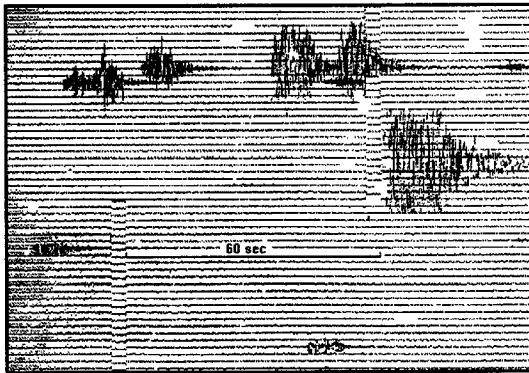


Fig. 3 A number of shallow volcanic earthquakes (B-Type) with high amplitude recorded on November 7th, 1992.

Observations on February 18 indicated that the eruption was no longer visible and the Anak Krakatau island was shaped like a sickle, opening to the southwest, and which had reached a height of 38 m above sea level. This event was declared by Stehn as a birthday of Anak Krakatau

Growht and evolution of Anak Krakatau since its birth has been well recorded by many scientists. The last growth in 1996 was estimated of about 300 m above sea level (Fig. 2), and the area extent more than 200,000 square m which has been developed by lava flows during the four years activity.

### 3. Cronology of the 1992-1996 Eruptions

#### 3.1 Pre-eruption, November 8, 1992

The last activity of Anak Krakatau before November 8, 1992 was the eruption in March 1988 as explosive eruptions as long as four months. The activity was preceded by increasing a number of volcanic earthquakes, more than 500 events of shallow volcanic earthquakes were recorded during 24 hours with magnitude MMI scale 2 - 3 before the first explosion occurred. The new vent was formed in the south flank, and the activity was ended by flowing down the lava flow to the south of about 100 m from the vent.

On August 17, 1992 an Observation Division Team from Volcanological Survey of Indonesia carried out a visual observation to Anak Krakatau, and changed the seismometer subsystem from MEQ-800 to PS-2 radio telemetric seismograph using L4 seismometer and equipped by TH-13's VCO. Visual observation surrounding the volcanic body of Anak

Krakatau indicated numerous of white vapor solfatara fields which its deposits covered the surface of the cone.

When the seismograph was installed, the deep and shallow volcanic earthquakes were recorded quite plenty, and the seismicity was dominated by the deep volcanic earthquakes but still in normal activity.

The first report of unusual activity of Anak Krakatau from the observatory, was received by VSI early of September 1992 when the number of volcanic earthquakes rapidly increased more over the normal activity, but in the end of September the seismic levels decreased again and quite within three days.

Elevated levels of seismicity were observed in early of October showing the seismicity changed into shallower volcanic earthquakes (See the histogram Fig. 6) and rapidly developed into an intense swarm on November 8.

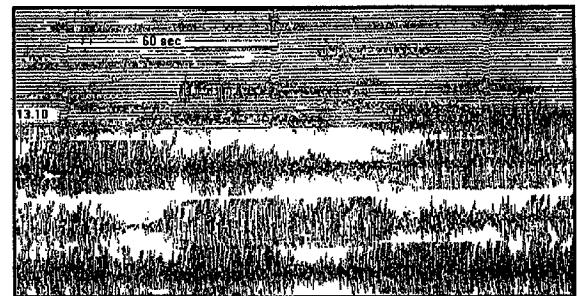


Fig. 4 Developing of intense swarm a few minutes before the eruption occurred at 13.10 (local time), November 8th, 1992.

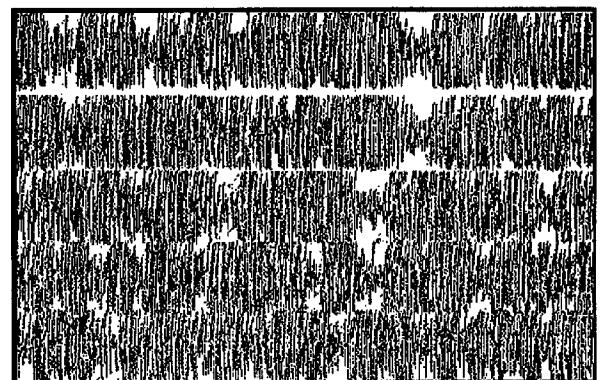


Fig. 5 Continuous explosion earthquakes that recorded after the first eruption, followed by the ash explosions.

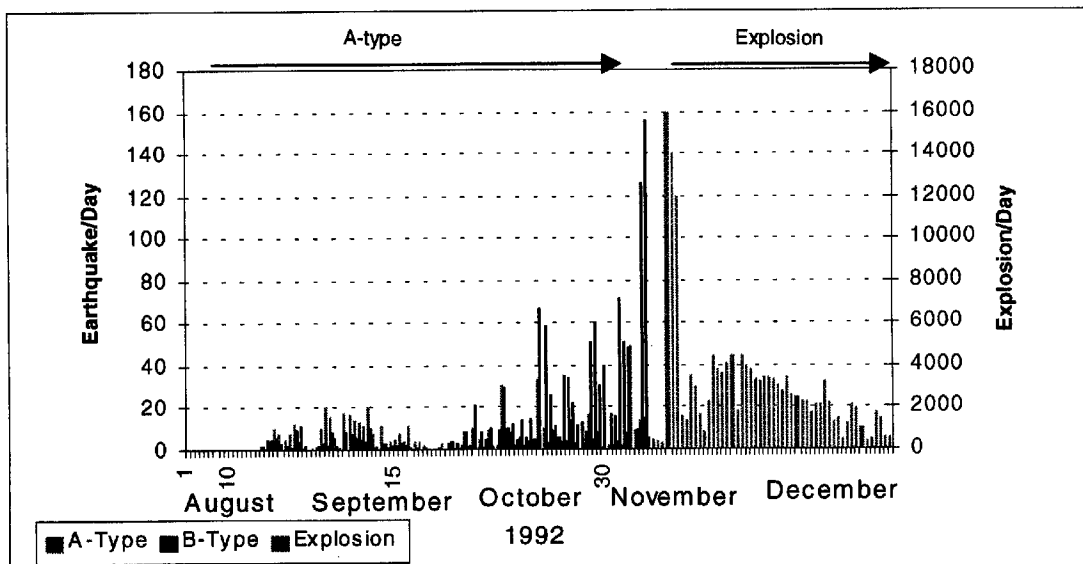


Fig. 6 A volcanic earthquake number that occurred before, during and after the first eruption, showing rapidly changes from deep to shallow earthquakes and ended by the eruption on November 8th, 1992. After the first eruption, the records were dominated by explosion earthquakes.

### 3.2 November 8 - December, 1992

Daily number of the shallow volcanic earthquakes rapidly increased beneath Anak Krakatau on November 7, and developed into an intense swarm on November 8 which recorded 400 events of volcanic earthquakes with magnitude MMI scale less than two. These events were recorded during ten hours before the first eruption. At 12.35 the swarm was more intense and developed into a volcanic tremor at 13.10 (see Fig. 4). The first ash column was seen by the observers at 13.31 from the observatory in Pasauran as high as 800 m above the summit. This first eruption formed a new vent in the north flank and mostly erupted old volcanic materials which spread surrounding the crater. Observation in the area on November 11 showed that the tephra deposits were found surrounding the crater of about 800 m in radius, consisted blocks mostly from the old volcanic rocks and ash. The lava flow was flowing down to the north as far as 300 m from the vent with 4-6 m thick in average.

The paroxysmal eruption occurred on November 12, at 19.15 that could be observed from the observatory of about 42 km in distance. Some explosive sounds were heard and followed by the glow of lava fountains during the night.

The second inspection was carried out on November 14, showed scattered bombs with 15 cm to 1.5 m in diameter laying on the surface within a

radius of 700 m. Hot fine ashes were burned a dry bush and leaves. The lava flow reached the north coast entering the sea as far as 50 m. In front of the lava flow showed the secondary explosions, due to interaction of the hot massive and sea water. During November 12, the seismicity was dominated by explosive earthquakes with high frequency and high amplitude.

The highest number of the explosive earthquakes was recorded on November 12 of more than 15,000 events appearing such as a volcanic tremor (Fig. 5). Magma beneath the volcano arose to the surface generating a strombolian eruption. The sound of the explosions were often heard in the observatory and along the Carita Beach, and the people could see the glow over the night from these places.

### 3.3 January - December 1993

The character of the eruption changed beginning 1993 from the intermittent explosive activity to the extrusion of viscous lava. Some visual observations from Krakatau Volcano Observatory during January to March 1993 showed dark ash columns with a height between 100 - 800 m and during the night was seen a glow of about 100- 400 m high above the summit. The seismicity was dominated by the explosive earthquakes and recorded of 31,930 events during January or about 1596 events per day (See the

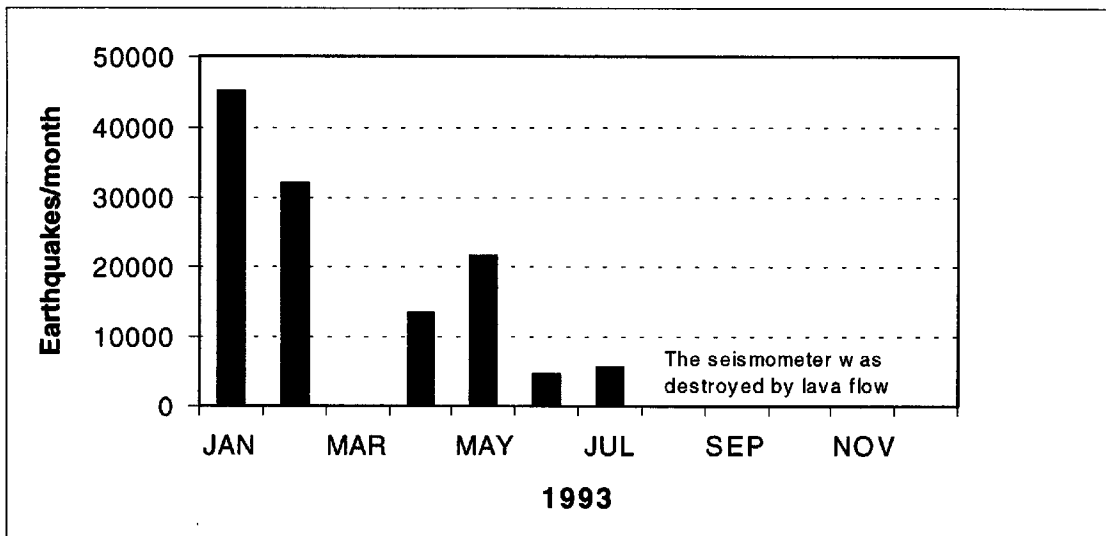


Fig. 7 Monthly number of the explosion earthquakes during 1993, some data was missing because of some troubles in the subsystem seismometer in the field.

histogram Fig. 7). Since February 21 the seismograph was not recorded the earthquakes because the seismometer subsystem in the field was destroyed by lava flow.

Topographic changed of Anak Krakatau was observed in March where the new cone has been built as high as 80 m from the formerly highest peak and the diameter of the crater developed of about 150 m to the south. Ash explosions occurred of a height between 200 - 500 m with interval between 2 to 10 menit. Seismicity during growth of the cone was characterized by the explosive earthquakes.

Huge lava flows arose in April to June. In April to May, the lava flows flowed down to the northwest and covered the November's lava. These lava flows entered the sea as far as 200 m extending the land. In June, the lava flows changed the direction that flowed to the northeast, filled the valley between the volcanic body and the old crater rim and overflowed passing the crater rim and flowing down to the northeast reaching the coast. The lava flow also entered the sea of about 150 m far. Besides the lava flows came out, dark ash explosion continued every 3 - 5 minutes with a height of 100 - 400 m above the summit. Lava glow and violent strombolian explosions occurred during the night.

During July to December, the eruptions were characterized by explosive activity with explosion average of about 700 m per day. Elevated explosive activity occurred in July where the ballistic bombs were erupted reaching the sea in a radius of about 1.5 km from the vent. In this case, the VSI and Gajah

Mada's seismometer subsystems were destroyed by the volcanic bombs. Meanwhile the new seismometer subsystem has not installed, VSI cooperated with Sakurajima Volcano Observatory, Japan to install an infrasonic microphone in Krakatau Observatory. This equipment was equipped by amplifier and recorder, which recorded the sensitive sound of the explosions comparing to the visual observations. From August to December, the seismic data was not recorded and the seismograph was fixed in March 1994.

### 3.4 January - December 1994

The Anak Krakatau activity during 1994 was characterized by explosive activity, no lava flow arose during this year. The third seismometer subsystem was installed in March, located in the southeast flank of about 50 m elevation above sea level. Monthly number of explosive earthquakes fluctuated during this year ranging from 2,000 to 16,000 events (Fig. 8) with the highest number occurred in August and decreased to the end of the year. Visual observation indicated that grey to blackash columns with 100 - 400 m high were continuous erupted producing loose pyroclastic materials to build the volcanic cone of Anak Krakatau volcano. Topographic changed during this year was indicated by rising the volcanic cone to a height of about 300 m above sea level, and the crater developed wider with a diameter of 200 m. Estimated calculation of the volume from lava flows and tephra deposits until 1994 was 13,760,250 cubic m and extending area of about 179,000 square m.

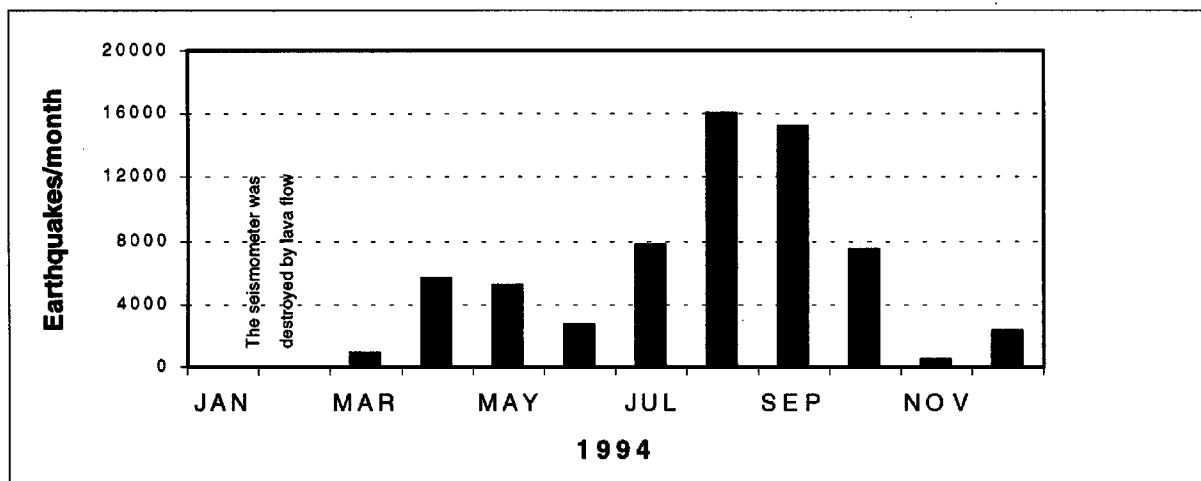


Fig. 8 Monthly number of the explosion earthquakes during 1994.

### 3.5 January - December 1995

A week decreased in seismicity preceded from January showing low levels explosive earthquakes with monthly number ranging between 2,000 to 8,000 events (Fig. 9).

The explosion interval ranged between five minutes to three hours producing dark to grey ash columns with a height of 100 - 400 m above the summit. North and east valley between the volcanic cone and old crater rim has been filled by lava flows and pyroclastic deposits.

Most of the lava flows that flowing down to the north and east directions, passing the slope of the old crater rim. Blocks and cow-dung bombs spread surrounding the volcano which has a diameter ranging from five centimeters to three meters.

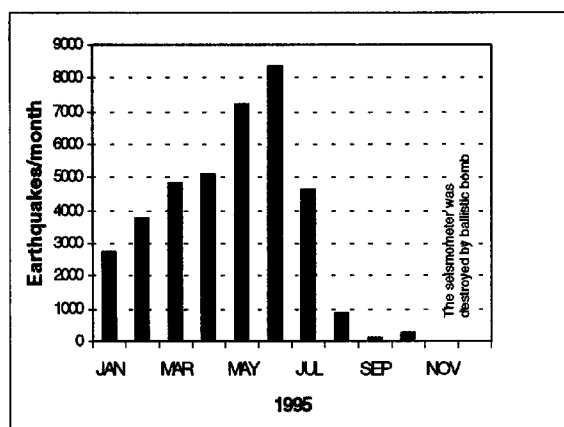


Fig. 9 Monthly number of the explosion earthquakes of Anak Krakatau during 1995.

Sporadic eruptions of strombolian type occurred in June causing a lot of branches of the trees were broken by the ballistic bombs, and some trees were burned by hot glow bombs. In the end of July, the seismometer subsystem was destroyed again by the rain of the ballistic bombs through the seismometer location. Probe of the antene broke and the house of seismometer subsystem damaged. During August to December, there were no seismic data, but visual observations could be observed from the observatory during day and night when the volcano was clear from the cloud.

### 3.6 January - December, 1996

During January to April, the seismometer subsystem has not been fixed because of the restricted seismograph devices but the lava flows could be observed during January that travelled from the vent to the south and followed the low topography to the west and another lava flow filled the valley. The subsystem was fixed in May and the sesimograph recorded more than thousand events of the explosive earthquakes during May, but early of June, the solar panel cable was cut by the ballistic bombs and caused loosing the seismic data until July, and the subsystem could be fixed in August. The explosive activity was intense in September and slightly decreased to the end of the year. During June and July, lava was extruded almost continuously to the north direction and the begining of July two new vent occurred in a distance of 50 and 100 m below the main vent. The last second vent produced numerous lava flows to the west direction and mostly entering the sea of about 100 m from the coast line. All of the vents showing

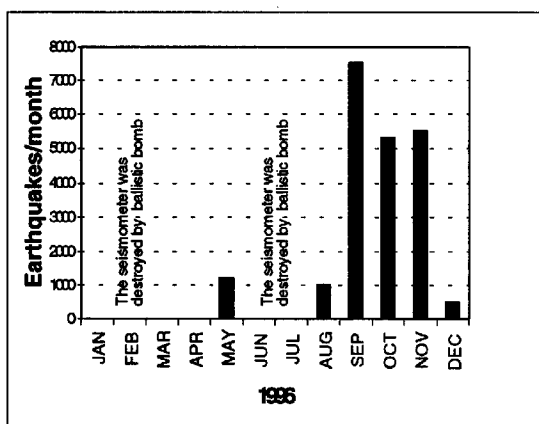


Fig. 10 Monthly number of the explosion earthquakes of Anak Krakatau during 1996.

the strombolian eruptions, mainly more clear scene at night. Temperature measurements of the edge July's lava flow is 760°C and the lava is basaltic andesite with a silica (SiO<sub>2</sub>) composition of 54.77 percent.

#### 4. Monitoring the 1992-1996 Eruption

Volcano monitoring is undertaken to assess the current status eruptive potential of the volcano and to document the occurrence and character of eruptions. The Anak Krakatau volcano monitoring only focused to seismic and visual observations. Seismic monitoring is the primary means of volcano surveillance, and it provided the basis for warnings issued by VSI during the Anak Krakatau crisis. The Anak Krakatau experience clearly demonstrated when the eruptions in 1981 and 1988 where the initial activity is preceded by increasing volcanic earthquakes and developed to an intense swarm or volcanic tremor.

##### 4.1 Field Observation

Visual observation of Anak Krakatau eruptive activity and investigation of volcanic deposits both on the volcano and its surrounding were essential for assessing the volcano activity and the hazards associated with it. The eruptive activity of the Anak Karakatau volcano is not directly disaster for the people who live surrounding the area and also the Krakatau Volcanic Complex is closed for people to live in it. Another problem is how to manage the tourists who visit Anak Krakatau during active, because no one guard in the area to protect their safety. During 1992, almost every eruptive activity of tephros or lava flows filled the valley between the old

crater rim and active cone, flowing down from the crater to the north and south coasts.

In 1993 the north and east parts of the valley have been completely filled by lava and tephra deposits, this caused the lavas of April to May 1993 over flowed the old crater rim toward northwest, and June 1993 another lava flow flowed down to the northeast crossing the the old crater rim and reaching the northeast coast. During 1994 to 1995 no lava flow flowed down but the eruptions were dominated by ash explosions that occurred more than a hundred per day. The lava flows continued flowing down in 1996, starting in January 1996 toward south and followed by another lava flow in June 1996 to the north. The last lava flow in 1996 occurred in July with huge lava flows which came out from the other vent (northeast vent) located about 200 m north from the main vent and flowed down to the west and northwest coasts. The distribution of lava flows since 1992 to 1996 is shown in Fig. 12. In July 1996, the vent developed

Table 1 The volume of eruptive materials of Anak Krakatau during 1992 to 1996 activity

No	Material	Month	Year	Volume (M3)
1	Lava	November	1992	289.000
2		February	1993	3.121.200
3		April-May	1993	2.132.820
4		June	1993	1.473.900
5		January	1996	1.456.000
6		June	1996	2.298.375
7		July	1996	4.356.600
8	Pyroclastic	1992 to 1996		6.743.330
Total				21.871.225

Table 2 Enlargment of Anak Krakatau Island during the Activity of 1992-1996 Eruptions

No	Material	Month	Year	Broaden (M2)
1	Lava	February	1993	20,000
2		April-May	1993	130,000
3		June	1993	29,000
4		January	1996	20,657
5		June	1996	23,370
6		July	1996	155,500
Total				378,527
Original broad				2,736,800
Additional broad				3,115,327

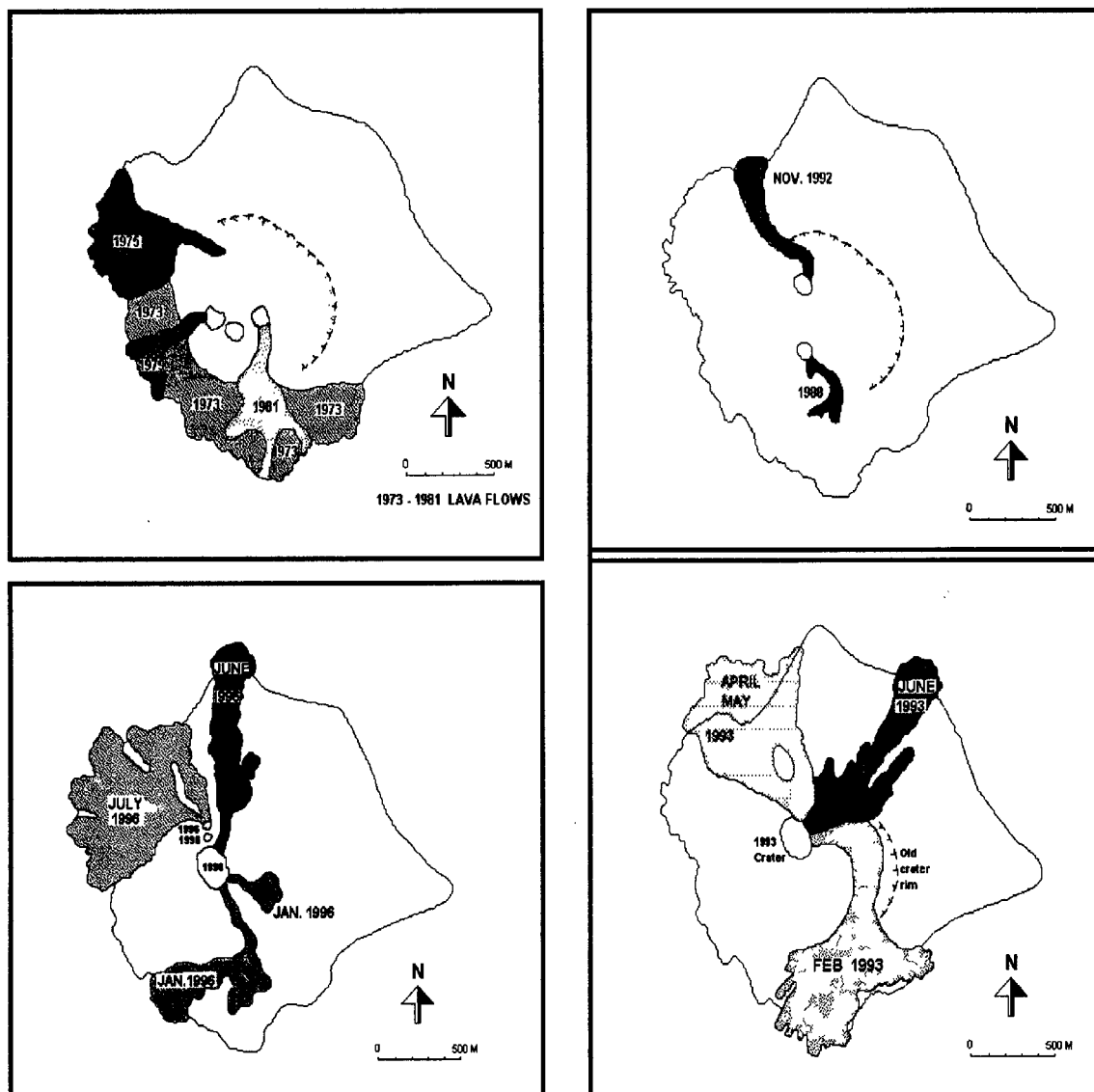


Fig. 12 The distribution map of Anak Krakatau's lava flows during the activity of 1992 to 1996 eruptions.



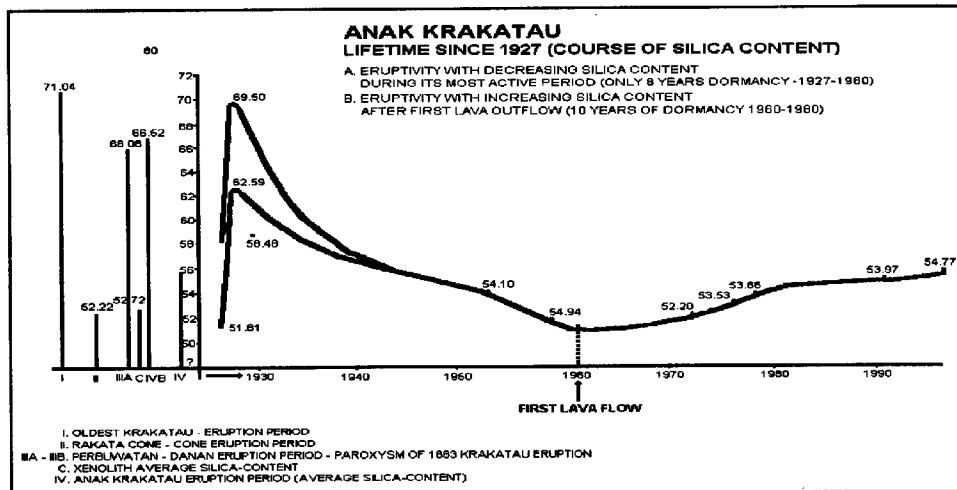


Fig. 13 Course of silica contents of Anak Krakatau lifetime since its birth 1927

into three eruption points in a row direction to the north from the main vent.

Today activity of Anak Krakatau is constructing the new cone by continuous strombolian eruptions of basaltic andesite tephra. It is about 300 m high from sea level and the crater developed toward south with 150 - 200 m in diameter.

Estimated volume of eruptive materials during 1992 to 1996 has almost 22 million cubic meter, is shown in Table 1, and roughly calculation is based on the distribution of lava flows and pyroclastic deposits. Beside the increasing of the height, most of the lava flows extended the land of Anak Krakatau.

Roughly calculations of broaden land by the lava flows is more than 378.000 square meter is presented in Table 2.

### 5. Future Eruption of Anak Krakatau

The eruptive history of frequent eruptions of Anak Krakatau is clearly imply that future eruptions are inevitable. Since its birth in 1929, many scientists carried out some investigations and even scare to the future paroxysmal eruption such as 1883. Bemmelen (1949) deduced that the paroxysmal eruption can occur again when the chemical composition of the magma beneath the volcano changed from basaltic to acid magmas, and Bemmelen mentioned that the dangerous eruption of Anak Krakatau generally is preceded by repose period of hundreds year.

Since its birth 1929 to now, Anak Krakatau has erupted more than seventy eight times. These eruptions

denote routinely activity of Anak Krakatau which occurred every year or every eight years and products of the eruption mainly lava flows, and have been chemically or petrologically analysed. The change of silica content from every eruption products have reminded De Neve(1981) to make a lifetime diagram of Anak Krakatau activity since the ancient eruptive products to the present (Fig. 13). De Neve plotted the diagram of the silica content until 1970's, separated into two blocks. Block A, eruptivity with decreasing silica content during its most active period, which has been ran only eight years dormancy since 1927 to 1960, and block B has continually plotted eruptivity with increasing silica content after first lava outflow, occurred for ten years dormancy.

Continually plotted of silica content in the diagram has been carried out since 1980 to the present activity. Each lava flows which has been mapped (Fig. 12) from several eruptions and showed that the silica content tend to slightly increase. Rock analyses of the Anak Krakatau's lavas as followed: November 1992 lava : 53.95 %, February 1992 lava : 53.53 %, June 1993 lava : 53.97, June 1996 lava : 54.77 % and June 1996 % of silica contents.

Plotted diagram shows that that the range of silica content tend to increase gently. If it is assumed that changes of silica content occurred one percent within ten years, so the 1883 caldera formation with silica content of about 68 percent, that can be reached in 140 years. This assumption should be supported by continuous analyzed of the Anak Krakatau eruptive products. If the silica content of the Anak Krakatau

eruptive products continue increase and than we can predict the next future activity of Anak Krakatau volcano.

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### 要 旨

1992年～1996年にかけて発生したクラカタウ火山の噴火活動について報告する。前兆となる地震活動は1992年8月17日から始まり、11月8日の最初の爆発の前には震源の浅いB型地震 (M<2) が群発し、爆発の直前10時間には400個以上が観測された。11月13日には規模の大きい爆発により山頂の北側に新たな噴火口が形成され、そこから流出した溶岩は北海岸に達した。また、高さ100mのスコリア・コーンが形成され、標高300mに達した。この噴火活動は現在も継続中であるが、以前ほど多量の噴出物を放出しているわけではない。1996年の7月には更に北側に3つの火口が形成され、最も北側の火口から流出した多量の溶岩は北岸及び西岸に達した。4年間の活動期間中に放出された噴出物量は1200万立方メートル以上と推定される。

キーワード：アナク・クラカタウ火山，火山活動，火山性地震，前兆現象，爆発的噴火，溶岩流